Modeling the effect of physiographic region on wood properties of planted Loblolly pine in Southeastern United States

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ABSTRACT

Specific gravity of Loblolly pine (*Pinus taeda* L.) 20 to 25 years old was determined using 12 mm increment cores collected from 74 plantations sampled across the Southeastern United States. X-ray densitometry was used to determine annual growth, proportion of latewood and specific gravity of earlywood, latewood and annual ring for 30 trees bored in each plantation. The relationship of physiographic region, latitude, longitude, summer precipitation, length of growing season and site index with annual growth, earlywood, latewood and ring specific gravity were examined. Annual ring specific gravity of Loblolly pine is highly correlated (r=0.88) with the proportion of latewood in the ring. The amount of latewood produced is dependent on the amount of summer precipitation (r=0.65) and length of growing season (r=0.52). Summer precipitation and length of growing season decreased from the Atlantic and Gulf Coast inland. Thus, specific gravity decreased with increasing latitude and increased with increasing longitude. Specific gravity also increased with increasing stand age and decreased with increasing site index. A regression equation was developed using stand age, latitude, longitude, and site index as independent variables to predict stand cross-section specific gravity at BH. The equation accounted for 79 percent of the variation in average stand cross-section specific gravity.

INTRODUCTION

The South produces 58 percent of the marketed timber in the United States and 16 percent of all timber marketed in the world (Wear and Greis, 2002). Loblolly pine (*Pinus taeda* L.) is the most important commercial species in the South and 35 percent of the timber harvested in the South comes from plantations. Loblolly pine is used to produce solid and fiber based products. The definition of Loblolly pine wood quality depends on the product for which the wood is used. Medium to high specific gravity (SG) is almost universally considered a desirable wood quality trait.

Wood SG increases significantly with age, especially in trees less than 30 years old because younger trees contain a larger volume of juvenile wood. Juvenile wood differs from mature wood in that has a lower SG, lower percentage of latewood, and shorter tracheids with larger microfibril angles (MFA ; Larson *et al.*, 2001). The length of the juvenile period of Southern pine increases from the southern portion of the range north. In Loblolly pine, the period of juvenile wood formation increases from 4 to 8 years in the Lower Coastal Plain to 10 to 14 years in the Piedmont. In a study by Cregg *et al.* (1988) it was observed that the transition from earlywood to latewood occurred one month earlier in a year of low rainfall and high spring evaporate demand than in a year of low evaporate demand and high rainfall. Whether an early transition to latewood leads to an annual ring with a high percentage of latewood, and thus high SG, depends on the growing conditions that occur after the transition to latewood production. Based on Moehring and Ralston (1967) it appears the moisture supply and pan evaporation in the months of July, August, September, and October are related to the amount of latewood that is produced. Specific Gravity (SG) variations associated with earlywood and latewood can significantly affect pulp yield, paper quality and strength and stiffness of lumber.

High SG is positively correlated with wood stiffness and strength, important properties for Southern pine lumber. High SG associated with mature wood also results in higher pulp yields and is generally associated with longer tracheids with increased tear for packaging papers (liner board, kraft sack). Low SG juvenile wood will generally have thinner walls and shorter tracheids, wider MFA and thus produce paper with good tensile, burst, fold and sheet smoothness but lower tear and opacity.

If the Southern pine wood industry could predict the SG of planted Loblolly pine stands across the range of the species the industry could better utilize the Loblolly pine resource. The objective of this research was to develop of model for predicting average stand SG from easy to measure independent variables such as stand age, latitude, longitude, and a measure of site productivity.

PROCEDURE

Loblolly pine plantations from Virginia to Florida were sampled to determine average cross-section wood SG at BH or 1.4 m above ground. Thirty-eight stands were sampled in the Lower Coastal Plain, 12 in Upper Coastal Plain and 24 in the Piedmont for a total of 74 stands (Fig. 1). Plantations selected for sampling were conventionally managed 20 to 25 year old stands that had not received any intensive management practices such as chemical competition control or fertilization except phosphorus in phosphorus deficient sites. The stocking of each stand was determined by inventorying all standing trees $\geq$ 12.7 cm DBH on three 0.04 hectare circular plots in each stand. Tree species, DBH, total height and crown class were recorded for each tree. Increment cores, 12 mm in diameter, were extracted from 30 trees in each stand. The trees bored were selected in proportion to the diameter distribution of the trees in the stand.

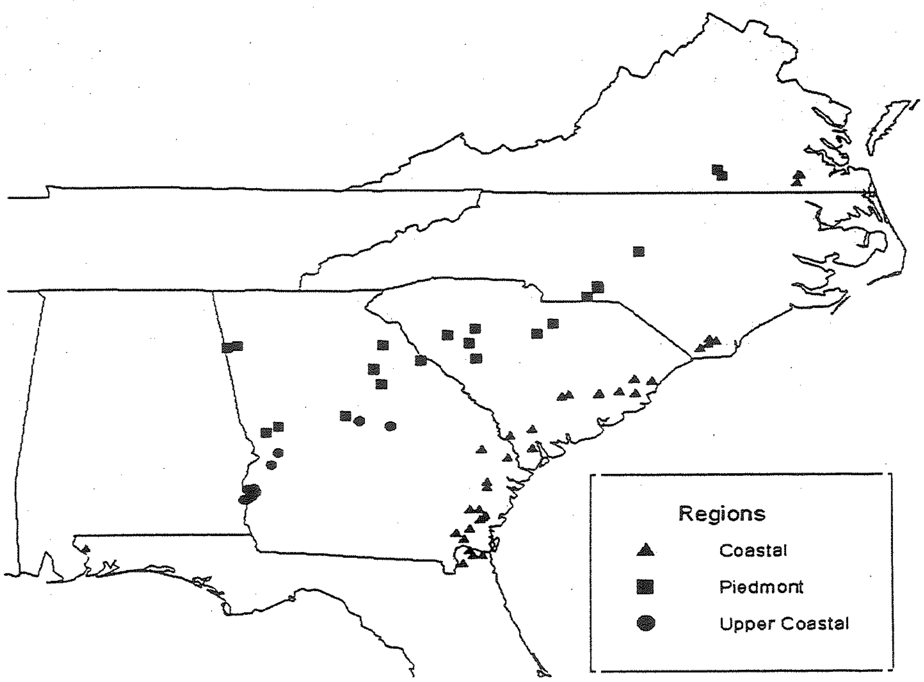

Figure 1 : Location of Loblolly pine plantations sampled to determine for increment core specific gravity in the Lower Coastal Plain, Upper Coastal Plain and Piedmont physiographic regions.

The increment cores were dried, glued to core holders and sawn into 1.6 mm strips. Radial growth of earlywood and latewood and SG of earlywood and latewood of each annual ring for each radial strip were determined at 0.06 mm intervals using an X-ray densitometer. A SG value of 0.480 was used to separate earlywood and latewood. The densitometer was calibrated to express SG on a green volume and oven dry weight bases. The transition from juvenile to mature wood was defined as the year in which percent latewood was greater than 40 percent and ring specific gravity was greater than 0.48. Ring SG was weighted by ring basal area to obtain a weighted cross-section earlywood, latewood, whole cross-section SG and weighted cross-section proportion of latewood for each tree. Cross-section SG was determined for age 5, 10, 15 and 20-25 by weighting rings 1-5 for age 5, ring 1-10 for age 10 and rings 1-15 for age 15, and rings 1-20 to 25 for age 20-25. Tree data were averaged by stand.

Monthly average, minimum, and maximum temperature, monthly precipitation, and annual number of growing days from 1976 to present were collected for each stand. Weather data were collected from a weather station within 48 kilometers of each stand.

An analysis of variance (ANOVA ; SAS, 1988) was run on the data to determine the effect of physiographic region on weighted cross-section earlywood, latewood, whole cross-section specific gravity and proportion of latewood. Region effects were assumed to be fixed and stand effects were assumed to be random. Statistical design included :

r = Regions : Lower Coastal Plain, Upper Coastal Plain, Piedmont,
s = Stands.

The general form of the ANOVA was :

Source	Degrees of freedom (df)	df
Regions	r-1	2
Stands (Regions)	r(s-1)	71

A correlation analysis was run to determine the correlation between stand SG, proportion of latewood, stand variables, geographic location and weather data.

Based on stand age, geographic location and site productivity the following regression model was developed to estimate average stand weighed cross-section SG :

$$SG = a + b\,(LAT) + c\,(LONG) + d\,(SI) + e\,(AGE) + f\,(\ln(AGE))$$

Where :

SG = average stand weighted cross-section specific gravity,
LAT = latitude of stand in degrees,
LONG = longitude of stand in degrees,
SI = site index of stand at base age 25 in meters,
AGE = stand age in years,
ln (AGE) = natural log of stand age.

RESULTS AND DISCUSSION

The Loblolly pine trees sampled for SG in the Lower Coastal Plain, Upper Coastal Plain and Piedmont were on average the same age however, average site index for the Lower Coastal Plain stands was higher than that of the Upper Coastal Plain or Piedmont. Thus, the trees sampled in the Lower Coastal plain were slightly larger in diameter and taller than those sampled in the Upper Coastal Plain and Piedmont (Tab. 1).

Table 1 : Average characteristics of Loblolly pine trees bored for wood specific gravity by physiographic region.

Region	Characteristics								
	Stands	DBH		Total Height		Site Index		Age	
	Sample	Avg	Range	Avg	Range	Avg	Range	Avg	Range
	No.	---------cm---------		--------m-----------		---------m----------		years	
Lower Coastal	38	24.1	15.5-30.0	20	16-24	23	17-28	22	20-25
Upper coastal	12	22.7	18.8-28.4	18	15-22	20	16-25	23	20-25
Piedmont	24	22.7	18.5-27.9	18	14-21	19	15-23	23	20-26

Plots of ring earlywood SG over rings from the pith show earlywood ring SG does not vary between physiographic regions and that earlywood SG does not change with increasing ring number or cambium age (Fig. 2). Average ring latewood SG also does not vary significantly among physiographic regions but does increase with increasing cambium age (Fig. 3). Plots of increment core annual ring SG over rings from the pith show SG increasing with increasing cambium age (Fig. 4). The plots show the normal juvenile/mature wood formation pattern for the three physiographic regions with low SG core-formed wood, formed in the first few rings, followed by a rapid increase in SG in the transition zone, followed by high SG mature wood. Based on the criteria used in this study to define the transition from juvenile wood to mature wood, the Lower Coastal Plain trees were on average producing mature wood by ring 6, the Upper Coastal Plain trees by ring 7 and the Piedmont trees by ring 8. Ring SG of the Lower Coastal Plain trees was higher than that of the Upper Coastal Plain or Piedmont trees. This regional difference in ring SG is not due to regional differences in earlywood or latewood SG but due to the higher proportion of latewood in the Lower Coastal Plain trees.

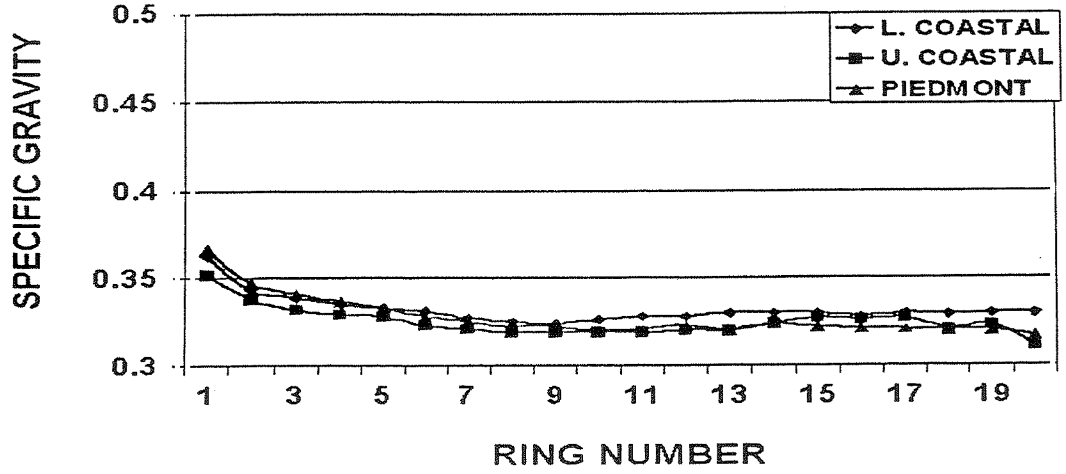

Figure 2 : Average annual ring earlywood specific gravity by ring number for 20-25 year Loblolly pine by physiographic region.

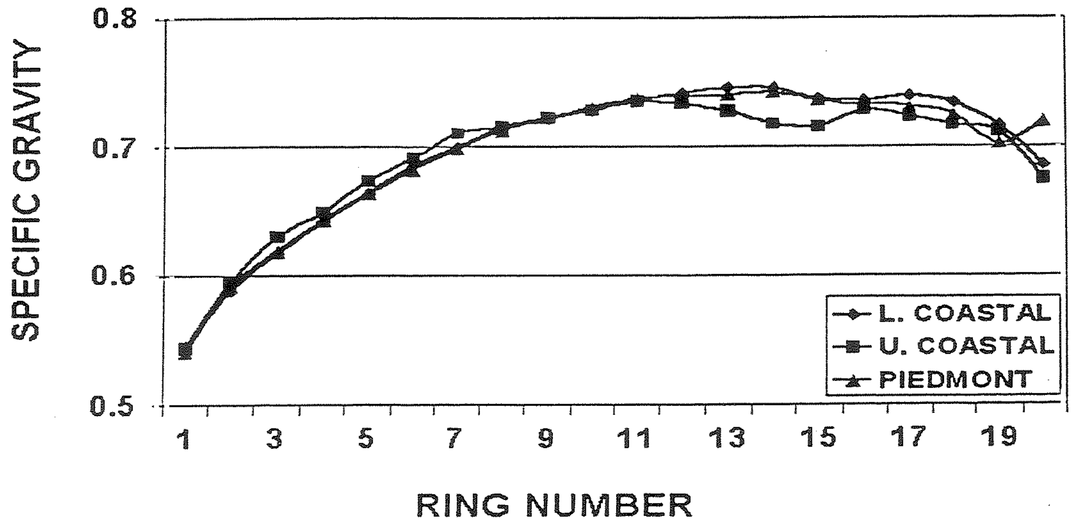

Figure 3 : Average annual ring latewood specific gravity by ring number for 20-25 year Loblolly pine by physiographic region.

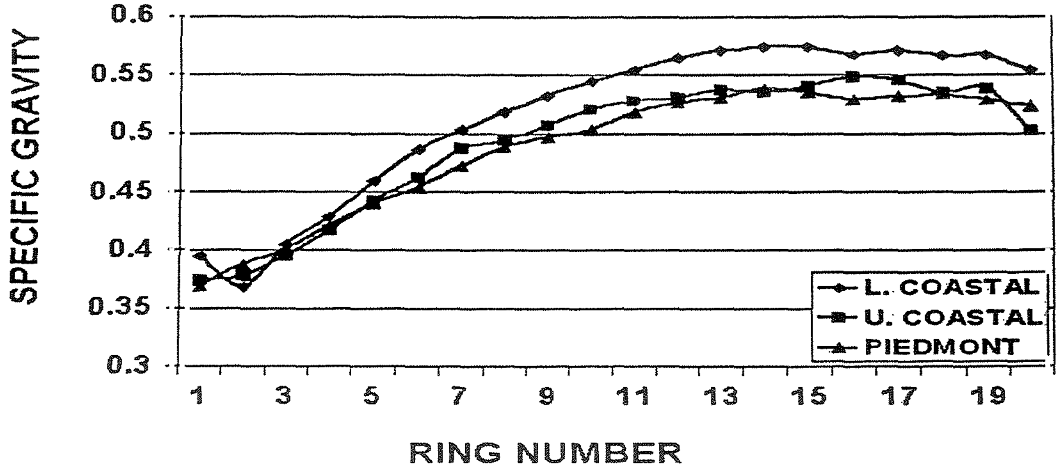

Figure 4 : Average annual ring specific gravity by ring number for 20-25 year Loblolly pine by physiographic region.

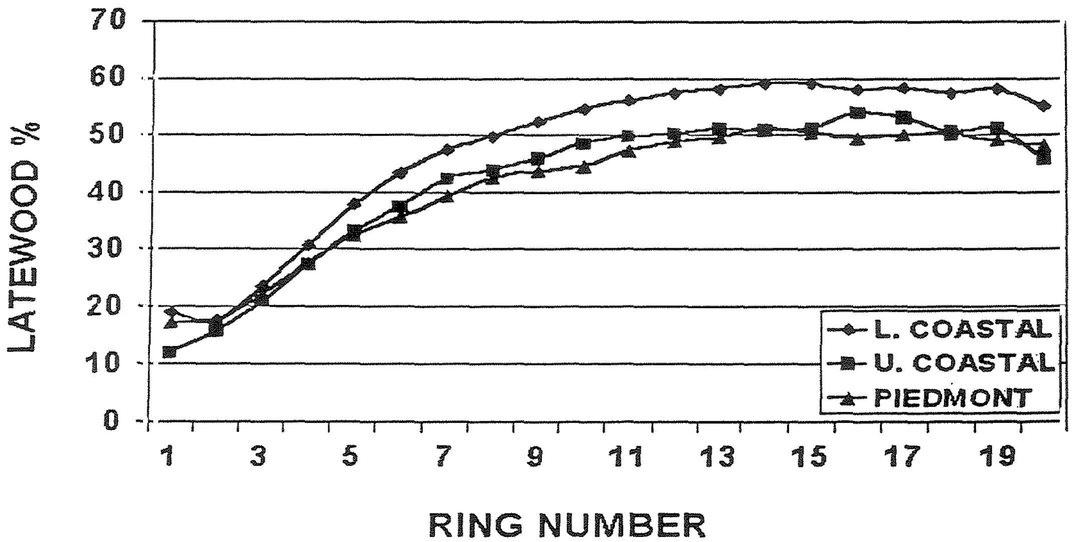

Figure 5 : *Average proportion of annual ring in latewood by ring number for 20-25 year Loblolly pine by physiographic region.*

The weighted cross-section SG of earlywood averaged across regions was 0.327. The ANOVA showed the earlywood SG of the Upper Coastal Plain trees to be significantly lower than that of the Lower Coastal Plain (Tab. 2). However, the difference of 0.008 in average earlywood SG between the Lower Coastal Plain and Upper Coastal is not significant from a practical stand point. Earlywood SG was statistically different because of the small variation in earlywood SG. The weighted cross-section SG of latewood did not vary significantly among regions and averaged 0.717. The SG of the whole cross-section was significantly higher in the Lower Coastal Plain (0.518) compared to that of the Upper Coastal Plain (0.487) or Piedmont (0.487 ; Tab. 2).

Table 2 : Average weighted cross-section specific gravity at 1.4 meters for 20-25 year planted Loblolly pine by physiographic region.

Region	Specific Gravity			Proportion
	Earlywood	Latewood	Whole cross-section	of latewood
				%
Lower Coastal	0.330a	0.719a	0.518a	48a
Upper Coastal	0.332 b	0.715a	0.487 b	42 b
Piedmont	0.326ab	0.714a	0.487 b	41 b

Values with a different letter are statistically different at the 0.05 level

Cross-section SG is significantly positively correlated with the proportion of latewood in the annual ring (Tab. 3). The amount of latewood produced is highly positively correlated with summer precipitation, average annual temperature, maximum December temperature, and number of growing days (Tab. 3). The Lower Coastal Plain receives on average 15 cm more summer precipitation in July, August, September and October, has a higher average annual temperature, a higher maximum December temperature than the other regions and 9 more growing days than the Upper Coastal Plain and 33 additional growing days compared to the Piedmont. Thus, the Lower Coastal Plain trees have more moisture for latewood production and produce latewood longer into the late autumn.

Table 3 : Correlations coefficients for weighted cross-section specific gravity with stand and weather variables.

	Cross-section SG	Early-wood SG	Late-wood SG	Percent late-wood	Stand latitude	Stand longi-tude	Site index	Summer Precip.	Avg. annual temp.	Max. Dec. Temp.	Growing days
	Correlation Coefficient (r)										
Cross-sec SG	1.0	0.59***	0.75***	0.88***	-0.40***	NS	0.24*	0.45***	0.47***	0.52***	0.48***
Earlywood SG	0.59***	1.0	0.34**	0.42***	NS	NS	NS	NS	NS	NS	NS
Latewood SG	0.75***	0.34**	1.0	0.39***	-0.32**	-0.12	NS	NS	0.27*	NS	0.27*
Percent latewood	0.88***	0.41***	0.39***	1.0	-0.38***	0.33**	0.44***	0.65***	0.51***	0.63***	0.52***
Stand latitude	-.40***	NS	-0.32**	-0.38***	1.0	0.57***	-0.62***	-0.38***	-0.94***	-0.84***	-0.79***
Stand longitude	NS	NS	NS	0.33**	0.57***	1.0	0.36**	0.31**	-0.37**	NS	-0.19
Site index	0.24*	NS	NS	0.44***	-0.32**	0.24*	1.0	0.56***	0.45***	0.57***	0.40***
Summer precip.	0.45***	NS	NS	0.65***	-0.38***	0.31***	0.56***	1.0	0.50***	0.68***	0.54***
Avg. annual temp.	0.47***	NS	0.27*	0.51***	-0.94***	-0.37**	0.45***	0.50***	1.0	0.92***	0.91***
Max Dec. temp.	0.52***	NS	NS	0.63***	-0.84***	NS	0.57***	0.68***	0.92***	1.0	0.81***
Growing days	0.48***	NS	0.27*	0.53***	-0.79***	NS	0.40***	0.54***	0.91***	0.81***	1.0

Values with * are significant at the 0.05 level ; values with ** are significant at the 0.01 level ; values with *** are significant at the 0.001 level.

Summer precipitation, average annual temperature, maximum December temperature, and number of growing days would be good independent variables for predicting average stand cross-section SG but these variables are difficult for a land manager to know for a stand. Stand location or latitude and longitude is highly correlated with these variables (Tab. 3) and easy for land managers to determine using geographic positioning systems.

Thus, the following regression equation using stand location, age and site index as independent variables was developed to predict average stand cross-section SG :

$$SG = 1.362104 - 0.013379*(LAT) + 0.007364*(LONG) - 0.002067*(SI) \\ - 0.003635*AGE + 0.100305*(\log AGE)$$

The equation had a coefficient of determination (R^2) of 0.79, a coefficient of variation (CV) of 4.1 percent, and a standard error of 0.019. All independent variables were significant at the 0.0001 probability level. The equation is easy to apply since a land manager will know the age of the stand, the stand's site index and the location of the stand.

CONCLUSIONS

Loblolly pine annual ring earlywood specific gravity does not vary with cambium age or from a practical stand-point by region. Specific gravity of annual ring latewood does increase with increasing cambium age but does not vary significantly among regions. Specific gravity of the annual ring increases with cambium age and is significantly higher in the Lower Coastal Plain compared to the Upper Coastal Plain or Piedmont. Lower Coastal Plain SG is higher because the trees contain a higher proportion of latewood. Lower Coastal Plain trees produce more latewood because they receive significantly more summer precipitation and have a longer growing season for latewood production.

Cross-section SG at BH is highly correlated with summer precipitation, average annual temperature, December maximum temperature and number of growing days. However, these variables are difficult to measure for a planted Loblolly stand but are highly correlated with stand location or latitude and longitude. Thus, an equation was developed to predict average stand cross-section SG using latitude, longitude, site index and stand age. These independent variables are easy to measure and account for 79 percent of the variation in stand cross-section SG.

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